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SUBMARINE BASE, GROTON, CONN.

REPORT NUMBER 989

CONTRAST SENSITIVITY MEASURED IN LOW LEVELS OF RED, WHITE, AND BLUE AMBIENT ILLUMINATION

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Naval Medical Research and Development Command
Research Work Unit M0100-PN.001-1014

Released by:

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Commanding Officer
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19 August 1982

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SUMMARY PAGE

THE PROBLEM

To determine whether the color of dim background illumination has an effect on the visibility of low contrast targets of various sizes.

FINDINGS

No differences were found between dim white, blue, and red background illumination in the detection of low contrast sine wave patterns presented both on a relatively dim and bright CRT screen. There were also no differences on the same task between these illuminant colors and a dark background.

APPLICATION

No support from a comprehensive psychophysical measure was found for the use of any one color of illumination in improving detectability of low contrast targets. These results will be important in determining optimal lighting parameters for submarine sonar shacks, where the detection of low contrast contacts on CRT displays is critical.

ADMINISTRATIVE INFORMATION

This research was conducted as part of the Naval Medical Research and Development Command Work Unit M0100-PN.001-1014 - "Optimum conditions for watch in sonar shacks." It was submitted for review on 16 Jul 1982, approved for publication on 19 Aug 1982, and designated as NSMRL Report No. 989.

PUBLISHED BY THE NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

ABSTRACT

Average contrast sensitivity functions were determined for six observers in the dark and under three colors of dim, ambient illumination. Measurements were taken with two different CRT screen brightnesses. The color of the illuminant did not affect the shape of these functions, or change sensitivity relative to a dark background. But the shape of the functions was changed by the screen luminance, consistent with other data in the literature. The frequent preference in submarine sonar shacks for blue light, over the customary red, is, therefore, due to factors other than enhanced contrast of the visual displays.

INTRODUCTION

Lighting conditions aboard submarine sonar shacks vary greatly both in quality and quantity of illumination. A recent survey has shown that although red light is still commonly used, some boats have recently converted to blue.[1] Others use no overhead lighting at all, relying only on stray white light from instruments. Most sonar technicians who have worked under the blue light prefer it, claiming that it enables them to "see better." Several possible reasons have been put forward to explain this preference: the psychological effect of responding favorably to any change, a greater amount of light, and a greater ease of accommodation. There is more effective illumination with dim blue than dim red light because of the shift in the spectral sensitivity of the eye toward the shorter wavelengths with decreasing illumination (Purkinje shift). A greater ease of accommodation occurs for blue light since it is composed of shorter wavelengths than the red. Consequently the light does not need to be refracted through as large an angle, lessening the strain for the accommodative mechanisms of older or farsighted individuals.

A preference for blue light may also be due to its enhancement of some visual function. It is improbable, however, that viewing under blue light results in better visual acuity than under red or white. In a review of factors influencing acuity, Westheimer claimed that, provided the luminances are matched, the wavelength used is of no consequence. On the basis of available evidence he concluded that chromatic aberration, or the focusing of different wavelengths at different distances, caused no degradation of acuity.[2] Two of the papers cited are particularly relevant to this study since the background illumination used was similar to that found in submarines. Luria and Schwartz,[3] measuring acuity at .34 fL, found no differences under red and white illumination. Shlaer et al.[4] showed no acuity differences at normal daylight luminance levels between red and blue light. There was some improvement with the blue at very low luminances, but this is interpreted as being due to the intrusion of the short-wavelength sensitive rods.[5] Rods affected the result since they are relatively more sensitive than the cones at low luminances. Furthermore the observers could freely view the target with the best part of their retina, in this case the predominantly rod-filled parafovea.

Although visual acuity does not degrade significantly with monochromatic light illuminating the target, complete isolation of cone mechanisms will show acuity differences between them. For example, when the blue cone mechanism is isolated it shows less acuity than the red and green cone mechanisms.[6,7] However if blue light is hypothesized to enhance visual functioning, this difference is in the wrong direction; moreover Stiles' two-color method for achieving this isolation involves strictly controlled viewing conditions which are not even approximate to those found in sonar shacks. Thus it appears that any differences between illuminant colors are unlikely to affect acuity. If vision is affected, a different measure of visual function is needed to demonstrate it.

Any visual object or stimulus

can be analyzed as the sum of a set of sine waves of different frequencies varying spatially in intensity--in other words, a sum of spatial frequencies. The sine waves are measured in cycles per degree of visual angle. Acuity refers to the detection of fine detail and so is limited to small sizes and hence the high end of the spatial frequency continuum. It remains possible that visual functioning is affected by illuminant color when one considers a wider range of spatial frequencies, particularly the lower ones (or larger sizes). In order to test this, it is necessary to compare the effect of the various colors of illumination on a measure of visual capacity that encompasses sensitivity over a range of spatial frequencies. This comprehensive measure is referred to as contrast sensitivity. The present study directly compares contrast sensitivity under red, blue, and white illumination, matched photopically, i.e., for light adapted eyes in bright light. A dark background condition was also included as an added control.

Contrast sensitivity is the reciprocal of contrast threshold at each spatial frequency. That is, it is the amount of contrast (or luminance modulation) needed for an observer to detect the sine wave gratings at the various spatial frequencies. Thus it is not limited only to those high frequencies representing acuity. This is important because under poor illumination, such as is found in sonar shacks, it is the lower spatial frequencies that remain salient while the higher ones degrade.[8] Therefore any real differences in the ability to detect objects of varying size and contrast which are dependent on the color of the ambient illumination, should show up as differences in contrast sensitivity to low and medium spatial frequencies.

METHOD

Observers. Data were obtained from one female and five male volunteer observers, all military or civilian staff members of the Naval Submarine Medical Research Laboratory. Four observers wore corrective lenses throughout the experiments. Two of the men were deuteranopes. All six participated in the first experiment and all but one man with normal vision participated in the second.

Apparatus. A Hewlett-Packard model 1311A cathode-ray tube (CRT) with a green P31 phosphor was used to present vertically oriented sine wave gratings. A function generator enabled the experimenter to adjust their spatial frequency. Contrast was varied in 4-dB steps by means of a decade attenuator which controlled the voltage output of the function generator. Contrast was measured with a Spectra Pritchard photometer and calculated according to the following formula: $(L_b-L_d)/(L_b+L_d)$, where L_b and L_d are the luminances of the bright and dark stripes, respectively. A timing circuit was added to control duration. A button-press thus flashed a grating of predetermined frequency, contrast, and duration on the screen.

Observers were seated directly in front of the screen at a viewing distance of 57 cm. The screen subtended a visual angle of 28°. In the first experiment the mean screen luminance was 1 fL. In the second experiment the mean screen luminance was .1 fL. These two luminances were chosen because they bracket the most common values of actual sonar displays.[9]

To provide the ambient illumination, a fixture holding two fluorescent lamps and fitted with an adjustable black cloth shield was positioned about five feet directly above the observer's head. In experiment 1 three colors of background illumination (red, white, and blue) were used in addition to a dark condition. In experiment 2 the three colored backgrounds were again used, without a dark condition. The white condition was provided by two cool white fluorescent lamps. The red and blue conditions were achieved by placing two red or blue plastic, tubular filters over the lamps. The spectral transmittance curves of these filters are shown in Fig. 1. The adjustable shield allowed the amount of photopic illumination falling on the screen to be equated in all three conditions. A value of .12 fc was chosen since it resides well within the range of ambient illumination found aboard submarine sonar shacks.[1]

Since this level of illumination was close to the mesopic range (the transition zone between light and dark adapted eyes in dim light), the photopically measured .12 fc value underestimates the relative visual effectiveness of the blue light and overestimates that of the red, due to the Purkinje shift mentioned above. The reasons for using photopic measurement are two-fold. First it is the accepted method for determining the amount of light stimulating the visual system and would be the means used by lighting engineers in making measurements in sonar shacks.

Secondly, no standard has yet been specified by the International Commission on Illumination for measuring light quantities in the mesopic range, although work is currently being done in this area.[10] According to one formula for calculating mesopic luminance provided by Palmer,[11] the blue light was about twice as bright as the red at .12 fc. For the dark condition all lights were turned off.

Procedure. In each experiment thresholds were determined for five spatial frequencies (.2, .5, 2, 5, and 10 cycles/degree) under each of the different lighting conditions. All observers were tested twice under each type of illumination, for a total of eight sessions per observer. The order of the lighting conditions was counterbalanced across subjects in the first session and then reversed in the second session. For four observers the dark condition was added after the start of the experiment, and so both dark sessions occurred last.

In a short practice session preceding actual data collection, observers were shown the stimuli to be used, and preliminary, approximate threshold values were located. This allowed for the selection of a set of four dB values, for each observer at each spatial frequency, that encompassed these preliminary thresholds. During the actual sessions, then, the thresholds for the five spatial frequencies were determined using the method of constant stimuli. Fifty stimuli were presented in random order: forty gratings and ten blanks. The forty gratings consisted of two presentations, at each of the four different dB settings, for the five frequencies.

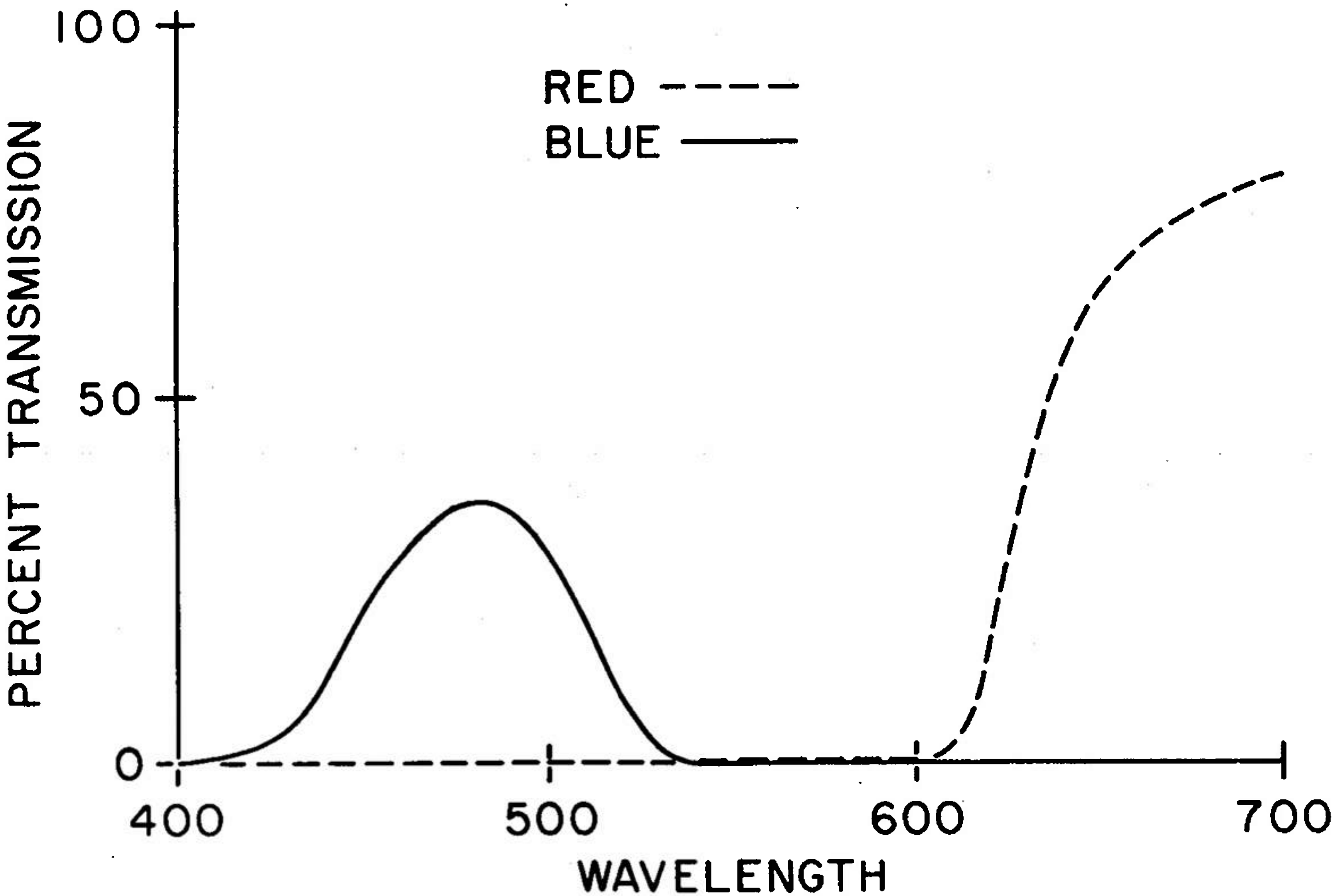

Fig. 1. Spectral transmittance of blue (——) and red (- - -) filters

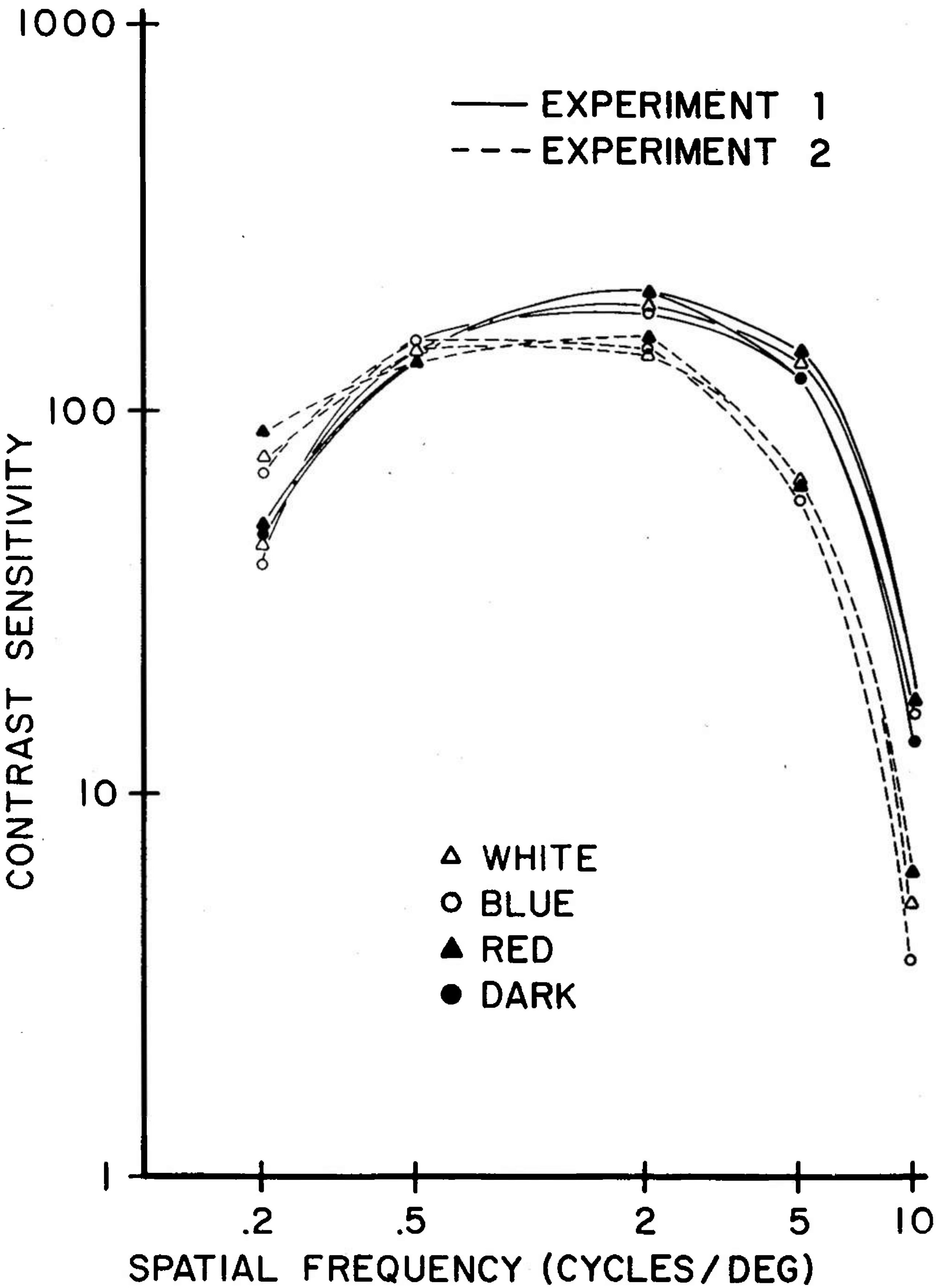

Fig. 2. Contrast sensitivity under four illumination conditions and two screen brightnesses.

Since spatial frequencies of less than 1 cycle/degree were used, the stimuli were flashed rather than presented continuously. This eliminates the possibility of local adaptation with such very low frequencies.[12] A duration of 500 msec was chosen, since it is brief enough to prevent this adaptation while not so brief as to decrease sensitivity to all frequencies. The experimenter gave a verbal "ready" signal before the gratings were presented.

RESULTS

The number of grating targets seen at each dB setting was tabulated for each observer. A "false alarm" is a positive response to a blank, while a "hit" is a positive response to a grating. For every two false alarms, one hit at the lowest contrast was changed to a miss in order to adjust for guessing. These data were then mathematically converted to thresholds and averaged across observers. The resulting average contrast threshold values for all spatial frequencies and lighting conditions are shown in Table 1 for the first experiment and in Table 2 for the second. It can be seen from the tables that the color of background illumination had little effect on the detection of grating targets, except at 10 cycles/degree. For a given spatial frequency, the means are similar across all four columns. Even the lack of any ambient illumination, the dark condition, resulted in no consistent, appreciable changes in thresholds. In both tables the greatest variability across illumination type is seen at 10 cycles/degree where the threshold is highest and observers frequently reported difficulty in seeing the gratings. The decrease in sensitivity shown under blue light for the 10 cycle/degree grating in experiment 2 is not significant due to the large inter-subject variability (standard deviation of .2 with a mean of .275).

The spatial frequency of the grating did, of course, have an effect on target visibility. Figure 2 shows these data plotted as contrast sensitivity, by color of illumination. For the first experiment the general shape of the functions, showing peak sensitivity around 2 cycles/degree, with reduced sensitivity for the low spatial frequencies and particularly for the higher frequencies, is consistent with other human contrast sensitivity data.[7] The functions from the second experiment show a marked decrease in sensitivity at the higher frequencies. This can be attributed to the ten-fold reduction in average screen luminance and so is in accordance with the drop in acuity found with lower illumination. It is also consistent with the expected loss in sensitivity at the higher frequencies with poor illumination that was mentioned earlier. Inspection of the individual data revealed no consistent differences between the deuteranopes and normals.

Two-way analyses of variance with repeated measures were performed separately on the individual data of experiments 1 and 2. The results show a main effect on detection threshold due to spatial frequency of the grating, no effect due to type of illumination, and no interaction. The spatial frequency effect is expected, as noted previously. The nonsignificant illumination effect fails to provide any support for the hypothesis that the color of

Table 1. Average contrast thresholds for six observers under various colors of illumination. Average CRT luminance of 1 fL, experiment 1.

	Color of Illumination			
Cycles/degree	White	Blue	Red	Dark
.2	.022	.025	.020	.022
.5	.007	.007	.007	.007
2	.005	.006	.005	.005
5	.007	.008	.007	.008
10	.057	.061	.057	.072

Table 2. Average contrast thresholds for five observers under various colors of illumination. Average CRT luminance of .1 fL, experiment 2.

	Color of Illumination		
Cycles/degree	White	Blue	Red
.2	.014	.015	.012
.5	.007	.007	.008
2	.007	.007	.006
5	.015	.018	.015
10	.181	.275	.160

illumination can enhance the detection of low contrast targets.

The inclusion of blank trials, in which the contrast of the grating was well below threshold, enabled an examination of the pattern of false alarms. The percentages of false alarms for experiment 1 are shown in Table 3. Although the relatively few number of blanks precluded a formal statistical analysis according to signal detection theory, it is evident that no regular pattern emerges. In the first experiment one observer had no false alarms at all, while for the other five observers combined, false alarms occurred with similar frequency under all conditions of illumination and at all spatial frequencies. There was large inter-observer variability for the number of false alarms under the different colors and also at the different spatial frequencies. There was also no consistent pattern for false alarms in experiment 2 (shown in Table 4). Two-way analyses of variance with repeated measures were also performed on these two sets of data. There were no significant main effects or interactions. These results indicate that the observers employed similar criteria for responding positively to a stimulus under the various experimental conditions.

DISCUSSION

It is evident from the data of Tables 1 and 2 that contrast sensitivity is not affected by the color of dim ambient illumination. Interestingly there was no significant difference between the blue and red conditions in both experiments, even though the blue light was more visually effective. Furthermore, when the ambient illumination level is as low as that found in sonar shacks, the results of experiment 1 show that it offers no significant advantage or disadvantage over no light at all, regardless of color. This is probably because the surface of the CRT reflects only a small portion of the incident illumination. Therefore, even though the lighted conditions represented an additional .12 fc of incident illumination over the dark background, this meant an addition of only about .03 fL to the luminances of both the light and dark stripes of the sine wave pattern. The addition of such light ordinarily tends to wash out contrast. The .03 fL value is so small relative to the average screen luminance of 1 fL in experiment 1, however, that accurate measurement proved contrast not to be significantly affected. With contrast the same, no significant change in threshold is seen with the dark and lighted backgrounds. This may not be the case for other levels of illumination or screen luminance. Therefore the conclusion that there is no difference in contrast sensitivity in the light and dark must be limited at present to the experimental conditions of low ambient illumination and a fairly luminous CRT screen.

Since there is also evidence that the color of the CRT phosphor has no effect on contrast sensitivity, at least for red and green phosphors,[13] neither display not illuminant color, by itself, appears to be a critical factor affecting visual function. One might expect, however, that certain combinations of illuminant and display color would either enhance or degrade visibility of the displays. For example, red light with red displays might tend to wash out the contrast that would be present with

Table 3. Percentages of false alarms for six observers under all conditions of illumination and at all spatial frequencies. Average CRT luminance of 1 fL, experiment 1.

Cycles/Degree	Color of Illumination White	Blue	Red	Dark	Mean	S.D.
.2	25	13	08	21	16.8	7.7
.5	13	17	08	13	12.8	3.7
2	25	13	13	04	13.8	8.6
5	0	13	13	25	12.8	10.2
10	25	08	17	17	16.8	6.9
Mean	17.6	12.8	11.8	16.0	14.6	
S.D.	11.1	3.2	3.8	8.1		7.1

Table 4. Percentages of false alarms for five observers under all conditions of illumination and at all spatial frequencies. Average CRT luminance of .1 fL, experiment 2.

Cycles/Degree	Color of Illumination				
	White	Blue	Red	Mean	S.D.
.2	15	05	10	10.0	5.0
.5	25	10	10	15.0	8.7
2	20	40	30	30.0	10.0
5	30	25	15	23.3	7.6
10	10	35	05	16.7	16.1
Mean	20.0	23.0	14.0	19.0	
S.D.	7.9	15.3	9.6		11.2

red light and green displays.

However the results of this experiment, in failing to find an effect of illuminant color on contrast sensitivity under conditions identical to those found in submarine sonar shacks, do not provide any psychophysical evidence for visual enhancement with colored light. Any existing preferences for blue light over red or white are evidently not based on any, as yet, demonstrated differences in visual function. The answer may yet lie in the greater amount of light provided by the blue under mesopic conditions.

ACKNOWLEDGMENT

We thank Dr. S. M. Luria for his critical reading of the manuscript and Mr. D. Douglas Wray for assembling of the testing apparatus.

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: NSMRL Report Number 989	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): CONTRAST SENSITIVITY MEASURED IN LOW LEVELS OF RED, WHITE, AND BLUE AMBIENT ILLUMINATION	5. TYPE OF REPORT & PERIOD COVERED: Interim report 989
	6. PERFORMING ORG. REPORT NUMBER: NSMRL Report No.
7. AUTHOR(s): David F. Neri and Jo Ann S. Kinney	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Naval Submarine Medical Research Laboratory, Naval Submarine Base New London, Groton, Connecticut 06349-0900	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 65856N M0100-PN.001-1014
11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Submarine Medical Research Laboratory, Naval Submarine Base New London, Groton, Connecticut 06349-0900	12. REPORT DATE: 19 August 1982
	13. NUMBER OF PAGES: 10
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): Naval Medical Research and Development Command, National Naval Medical Center, Bethesda, Maryland 20814	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Contrast sensitivity; blue lighting, red lighting

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Average contrast sensitivity functions were determined for six observers in the dark and under three colors of dim, ambient illumination. Measurements were taken with two different CRT screen brightnesses. The color of the illuminant did not affect the shape of these functions, or change sensitivity relative to a dark background. But the shape of the functions was changed by the screen luminance, consistent with other data in the literature. The frequent preference in submarine sonar shacks for blue light, over the

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